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Households in the smart grid – existing knowledge and new approaches

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For decades, electricity has generally been produced and available in western societies whenever consumers needed it and consumers could consume without thinking about it. This may not be the case in the future as new relationships between electricity consumers and producers are emerging. Electricity producers as well as transmission and network operators are increasingly interested in influencing the timing of when and how consumers use electricity, and in micro-generation by households (for instance from small wind turbines or photovoltaic solar panels). These changes are closely related to the so-called smart grid debate. In this chapter we will describe and analyse some of these technological changes within the electricity system, which is promoted by different actors, and we will discuss how this may influence the everyday life of consumers as well as the reverse; how everyday practices of consumers may influence this socio-technical system.

What is the smart grid?

It has already been expected for some years that the future of electrical grids will involve increasing use of information and communication technologies (ICTs) at all levels of the electricity system, including the production, distribution and consumption sides. The main drivers are new possibilities within ICT and new challenges within the energy system. One of these is the challenge of balancing electricity consumption and electricity production. Typically, most households have high electricity consumption at particular times, e.g. the peak between 17:00-19:00 in the evening when people return from work and turn on their electrical appliances in the home and start preparing dinner. Providing and distributing enough electricity for this type of peak is expensive, technically demanding and environmentally problematic. A possible solution could be to use ICT to better balance electricity production and consumption. Furthermore, introducing more renewable energy such as photovoltaic solar panels and wind power into the system implies that electricity production may fluctuate even more.

"Smart grid" is a term used to describe this future responsive and balanced energy system. Comparing similarities and differences between the approach to smart grids in the EU and the US, Coll-Mayor et al. (2007) show how contextualized the smart grid discussion is. Questions related to energy security and policy, including dependence on own vs. imported energy, type of energy market, type of existing energy production system, environmental and climate issues etc., are all influencing what grid developments are needed or could be expected.

Even though there is some agreement on what is meant by the smart grid, the term is an often cited catchphrase, which is vague and open in its definitions. One attempt to be explicit about what is meant by smart grid is found in Wissner (2011). According to Wissner, central factors are: liberalization of the telecommunication market with new competitors searching for new business models together with technological innovations, including appliance-integrated microchips, digitalization of networks and all sorts of wireless communication which enable different types of ambient intelligence including automation of everyday processes and activities. Thus, a possible future scenario of the smart grid includes a network of central power plants, wind turbines and other decentralized power generation, combined in an intelligent structure with houses that can produce, use and store energy, depending on the overall system requirements.

These changes in the power grid are inscribed in a long-term perspective, as the existing energy system is characterized by stability and lock-ins in both social organization and technology. Furthermore, based on a transition theoretical perspective with a multilevel framework on major technological transitions in infrastructures, Verbong and Geels (2010) show that other possible futures might be alternatives to the smart grid. For example the "super grid", a grid where all European countries are linked together and electricity is transmitted over long distances rather than adjusted to local energy resources. However, as demonstrated in this chapter, there are already many existing activities from different stakeholders that aim to promote the smart grid in order to overcome the inertia of the existing system.

Households in the smart grid

A very important element in the smart grid is the households and the consumers, who are expected to have a much more active role in the future energy system. This can include household-based electricity production, energy storage in batteries or as heat in the house and "flexible electricity consumption" (load management). The latter implies moving electricity consumption by moving energy consuming activities like electric heating, charging of electric vehicles or laundering to times with high electricity production or "peak shaving", i.e. shifting demand from "peak times" to times with lower demand. Load management in particular implies the active participation of consumers. Not all types of electricity consumption are suitable for load management; watching television and lighting, for example, cannot be postponed. Therefore, the focus in these areas should remain on efficient technologies to reduce consumption. Both energy efficiency of appliances and load management are important approaches in reducing CO_2 emissions (Vidalenc and Meunier 2011).

As it seems that smart grids in some form will be part of the future electricity system, and as consumers have a prominent position in the conceptualizations of the future smart grid, it is important to study the role and consequences of the smart grid for the future everyday life of consumers, as well as the opposite: how the everyday life of consumers might influence the smart grid. In the following we will first briefly discuss how consumer practices in changing socio-technical systems can be understood. Then follows a review of smart grids activities in Denmark as an exemplification of the type of activities that are occurring and how households are included in these activities. Then follows a section with a specific focus on electric vehicles, which are expected by many actors to play a particularly important role in the smart grid. Based on the review and the discussion of electric vehicles, we conclude by discussing the most relevant research questions and problems related to this possible future, from a consumption research perspective.

Understanding consumer practices in socio-technical systems

Consumers' sense-making of everyday consumption is not done in a vacuum. Rather, their consumer practices are interwoven with socio-material systems, linking production and consumption together and including other social actors as well as material objects. Electricity consumption is a particular type of consumption. Together with other types of consumption based on large socio-technical infrastructures such as heat and water consumption, electricity consumption is on one hand invisible and inconspicuous, depending on routines and habits, and on the other hand a fundamental prerequisite of our modern way of living. It can be argued that we do not *consume* electricity as such, but rather perform practices through which electricity is consumed during the use of household appliances. Everyday practices of cooking, laundering, watching television etc. must be seen in relation to the production system of all of the material objects used in these practices, as well as in relation to the production of the electricity, which is a fundamental element of performing the practices (Vliet, Chappells and Shove 2005). Practice theory was introduced into consumer studies some years ago (Shove and Pantzar 2005; Warde 2005), and since then there has been a growing body of research using practice theory to understand everyday practices and their connection to energy consumption (Gram-Hanssen 2010a, 2010b; Hargraves 2011; Strengers 2010, 2011). This approach focuses on the collective aspects of practices, seeing the individual as a carrier of practices rather than as an individual deciding what to do. Furthermore, practices are seen as guided by competences, rules, technology and meanings. This approach of practice theory is thus well suited for understanding how socio-technical systems, e.g. electricity production, influence the everyday practices of households. In this chapter we are interested in the changes that are taking place within the production side of the electricity grid, promoted by different types of actors, as it seems that these will have a significant impact on the consumer side of this socio-technical system, specifically the everyday practices performed by individual households.

Danish household smart grid activities – seen in a European context

As described in the introduction, the national context, including the local electricity system and energy policy, is decisive for challenges and solutions within smart grid development. In this section, we will give a brief overview of the Danish household smart grid activities, including the rollout of advanced metering infrastructure (smart meters) as well as previous and current smart grid projects related to households. We begin with a short introduction to the Danish electricity system, which forms an important context for understanding the Danish smart grid activities related to households.

The Danish electricity system

Fossil fuels, mainly coal and natural gas, dominate Danish electricity production as primary energy sources, and about half of the electricity comes from combined heat and power production (Danish Energy Agency 2011). However, by 2020, the Danish energy agreement aims to shift 50% of electricity production to wind power. This increasing share of fluctuating wind power in the electricity system poses new challenges in relation to balancing the input and output of the electricity grid. Wind power production already exceeds domestic electricity consumption at times with high wind speeds and low domestic consumption. This has given rise to an interest in developing solutions to manage the consumption side. Through load management, electricity consumption can either be delayed in situations of low wind power generation or moved forward in cases of excess wind power. Hitherto, the focus has particularly been on electric vehicles and electric heating of buildings as objects of load management.

The metering infrastructure

The rollout of "smart meters" is regarded as pivotal for the development of an advanced metering infrastructure that is expected to be the backbone of the future smart grid. Smart meters are electric meters that enable two-way communication between the meter and other actors in the electricity system (e.g. distribution system operators) and record electricity consumption in intervals of an hour or less. Smart meters are typically a technological prerequisite for feedback to customers about their electricity consumption and for load management. Furthermore, the remote reporting feature of smart meters is regarded as a more cost-effective alternative to the traditional meters that included considerable administrative costs in relation to reading the meters.

A 2011 survey by the Austrian Energy Agency of the status of the national regulation and implementation of smart meters in the EU27 Member States and Norway (Renner et al. 2011) shows great differences between the European countries. In some countries a mandatory rollout of smart meters to all customers is already in place or in preparation (e.g. Italy, France, Malta and Spain). However, most Member States do not yet have a mandatory rollout in place, even though some countries do already have a high degree of implementation of smart meters. Denmark is an example of this: by 2011, an estimated 50% of Danish households already had smart meters and remote reading installed (Renner et al. 2011). With the rollout of smart meters, one solution in relation to "activate" consumers is to regulate energy consumption using dynamic electricity prices. Today, households' electricity consumption is paid for according to average expenses and includes a considerable element of tax. Dynamic pricing would presumably give a more precise signal of "real-time" expenses and might mobilize consumers by increasing the incentives to change temporal consumption patterns.

Status of Danish household smart grid activities

In this section we present a brief survey of the Danish household smart grid activities based on a study by the Joint Research Centre (2011) and our own review of existing projects. The survey shows (table 1) that load management is the area that attracts the most attention in relation to Danish research & development and demonstration projects, particularly in relation to electric heating (heat pumps or direct electric heating) and charging of electric vehicles. Both areas are expected to become increasingly important for the Danish electricity system in the coming years, due to an expected substitution of oil-fired central heating with heat pumps in single-family houses outside district heating areas and an expected substitution of traditional cars with electric vehicles. Both are seen as part of the change from fossil fuels to carbon-neutral fuels and as a prerequisite in itself for building the needed storage capacity in the future smart grid with a high share of wind power. However, a number of projects also have a more general approach to residential electricity consumption, i.e. not focusing on one particular area.

As noted by Nyborg and Røpke (2011, 7), the question of who should manage consumption in order to provide flexibility – the consumers themselves or the electricity companies through remote control – is one of the core issues in the discussion about load management. The Danish load management projects reflect this diversity. Some projects focus on *automated remote management* of appliances. Other projects focus on *motivating consumers to change their practices* (e.g. defer their laundry or dishwashing) in response to information about real-time electricity prices.

	Electricity saving	**Load management**	**Micro-generation**	**Power capacity**	**Other**
Heating/air cond.		* Price-sensitive electricity cons. in households * EcoGrid EU * eFlex * Intelligent remote control of heat pumps * Trials with heat pumps on spot agreements			
Cooling					
Laundering					
Cooking					
Lighting & other appliances					
Transport		* EDISON * EcoGrid EU * eFlex * Intelligent charge stands * Test en elbil			* Test en elbil * Better Place * Etrans
Household electr. cons. in general	* ConsumerWeb * EcoGrid EU * Intelligent home * EnergyFlexHouse * Feedback-motivated energy savings * Several “feedback light” solutions in relation to smart meters (provided by DSOs)	* eFlex * iPower * Energy Forecast * FlexPower * EnergyFlexHouse	* EnergyFlexHouse		* IMPROSUME
Other					* Innovation Fur

Table 1: Danish household smart grid projects by type of smart grid activity and consumption area

An example of automated load management is the "Intelligent remote control of heat pumps" project, which aims to develop and demonstrate an intelligent remote control system for individual heat pumps through trials involving up to 300 households (http://www.styrdinvarmepumpe.dk). Examples of active involvement of consumers are the eFlex project (by DONG Energy) and the FlexPower project (by SEAS-NVE in cooperation with Ea Energianalyse and others). The eFlex trial finished in 2012 and involved about 120 households (predominantly households with heat pumps, but also a few with electric vehicles as well as some without heat pumps or electric vehicles). The test families were equipped with the home energy management system GreenWave Reality, which enabled feedback at appliance level, apps for smart phones and remote control of appliances. During the test period, the families were offered real-time dynamic prices, which meant that the electricity price varied by up to 1 DKK/kWh (the normal Danish electricity price is about 2 DKK/kWh). The project showed, among other things, some potential for load management in relation to heat pumps, but also limitations to this potential such as in periods of extraordinarily cold weather. Finally, some projects included both automated remote management and active involvement of consumers. One example of this is the research project "Price-sensitive electricity consumption in households", which included about 500 households divided into one control group and three test groups, including a test group with automated remote control of their direct electric heating system and a group that was notified about the next day's electricity prices by e-mail or SMS on a daily basis. The study showed that only the first test group had realized actual economic savings through load management (Togeby and Hay 2009).

Electric vehicles are considered by many actors to play a particularly important role in the future Danish smart grid. The idea is that with the (expected) penetration of electric vehicles, these will represent considerable storage capacity for electricity. At times with high power production (e.g. due to high wind speeds), the electricity surplus (or some of it) can be stored in the batteries of electric vehicles through intelligent management of the charging. At the time of the COP15 summit in Copenhagen, two major electric vehicle demonstration projects were launched: "Better Place" and "Test-an-EV". Both projects aimed at introducing electric vehicles to the Danish market and promoting sales, the projects differ with regard to the basic battery charging design. While the "Test-an-EV" project made use of traditional electric vehicles, the "Better Place" project developed a design with switchable batteries; thus, the car battery could be recharged at home, at the work place or at another charge station (as with "traditional" electric vehicles), or the depleted batteries could be replaced with new, fully-charged batteries at special designed "battery switch stations". The latter solution was developed in order to solve the problem of limited battery capacity and the problem of time-consuming recharging of batteries. "Test-an-EV" took another approach to the problem of limited driving distance between recharge, as they have been building a network of "Quick Charge" stations across Denmark. At these stations, electric vehicles can be recharged in only 20-40 minutes (compared to a normal recharging typically taking up to 5-6 hours).

In spring 2013, Better Place went bankruptcy due to failing car sales, wheres the Test-an-EV project is still running. Both projects relate their activities to the aim of developing a smart grid where electric vehicles play a particularly important role in load management. However, until now with a main focus on popularizing the electric vehicle and promoting sales.

With regard to electricity saving and feedback, almost all customers with a smart meter have access to some kind of feedback services, although the extent of these services varies considerably among electricity companies. The minimum service, provided by nearly all companies, is offering the customers the possibility of accessing data about their household's electricity consumption based on hourly readings. In addition to this, some also offer services like applications (apps) for smart phones that can be used to monitor the household's electricity consumption, or receiving alerts by SMS or e-mail if the electricity consumption is higher or lower than usual. Even though in principle almost half of Danish households have access to some kind of feedback about their household's total electricity consumption, it is still uncertain how great an impact (if any) this has had in terms of actual electricity saving. International research suggests that there is little evidence that this type of feedback to customers will automatically achieve a significant reduction in energy demand (Darby 2010).

While the main focus of the Danish household smart grid projects is on electricity saving and load management (table 1), only one project (the EnergyFlexHouse project) includes tests of household-based "micro-generation" technologies such as photovoltaic solar panels, and no projects focus on households as suppliers of "power capacity" to the grid in situations with a deficit of electricity (e.g. electric vehicles delivering electricity back to the grid). While most of the load management projects focus on electric heating or electric vehicles, electricity saving projects in general have a broad focus on electricity consumption in households.

The number of smart grid projects in Denmark is high compared with other European countries, including Norway (Joint Research Centre 2011). The size of projects varies considerably, but most projects are relatively small, with a total budget of only a few million DKK. However, the list of projects also includes a few large-scale demonstration projects (e.g. the previously mentioned Better Place and Test-an-EV). The largest project is the EcoGrid EU project, launched in 2011 and running until 2015, with a total budget of 21 million euro. EcoGrid EU is expected to be the largest European full-scale testing of smart grids so far (Nyborg and Røpke 2011). The project is based on the island of Bornholm and includes many different smart grid solutions (e.g. "intelligent charging" of electric vehicles and load management in general) and involves at least 2,600 households (Energinet.dk 2012).

The electric vehicle: an important technology in the smart grid

As electric vehicles are expected by many actors to play a particularly important role in the future smart grid, and as they are an emerging technology, this section will present the latest developments in electric vehicles (including challenges and advantages) and review existing studies on consumer adoption of electrical vehicles.

The state of electric vehicles: advantages and challenges

To establish electric vehicles as a serious alternative to traditional internal combustion engine cars, manufacturers have primarily focused on improving performance. Companies like Toyota, Citroën, Peugeot, Honda, Mitsubishi, Renault etc. are at the forefront of developing different prototypes of electric vehicles. Now that electric vehicles are competitive with traditional combustion engine cars in relation to acceleration and car size, the focus has turned to solving two critical issues: 1) the driving distance per recharge, and 2) production costs. The vehicle-to-grid configuration of electric vehicles features three operation elements: a power connection to the grid, a control/communication device and a meter (Sovacool and Hirsh 2008). To solve problems with the limited driving distance, a geographically distributed recharge infrastructure is necessary (like the "Quick Charge" stations of the Test-an-EV project or the "battery switch stations" of the Better Place project). Infrastructural changes progress slowly as the incorporation of electric vehicles into the market is a long-term goal. This means that electric vehicles will not be fully competitive with traditional combustion cars until a recharge network has been established, so that consumers can cover longer travel distances (Sovacool and Hirsh 2008).

Also, the interface to the grid is attracting more focus and standardization is becoming an important issue. The European Commission has issued a mandate to ensure consistent standards within the EU, and while this was previously driven by the utilities, the car manufacturers are now also taking part in that process.

Electric vehicles have many potential advantages. Some arguments for electric vehicles are their mechanical simplicity, ease of use and perception as environmentally out-performing traditional cars (Dickerman and Harrison 2010). "Soft" characteristics such as improving comfort and safety are also becoming a selling point (Sovacool and Hirsh 2008). In this regard, the main barriers facing electric vehicles are not only technical or economic; significant factors could also be social and cultural values, business practices, political interests etc. (ibid).

Consumer adoption of electric vehicles

The literature on consumer adoption of electric vehicles is dominated by the rational choice approach and thereby a focus on economic and instrumental barriers and how these can be translated into policy (Sovacool and Hirsh 2008). However, vehicle trials are beginning to see uptake processes that are more complex and slower than the economic approaches suggest. A study by Heffner et al. (cited in Sovacool and Hirsh 2008) based on interviews with early purchasers of electric vehicles in California found that savings from fuel efficiency constituted only a small part of the reason for adopting electric vehicles. Accordingly, some studies advocate a better understanding of consumer preferences, habits and incentives in the adoption of electric vehicles. Analyses of consumer adoption claim that consumers in general have different patterns of adoption and use, have different attitudes, relate different meanings to electric vehicles and evaluate the attributes of the car differently.

Correspondingly, a study of driving patterns and electricity supply systems in the US (Weiller 2011) demonstrated significant variation between different regions and between different states. This led to a broader conceptualization of segmentations, with the conclusion that there is more than one group of early adopters of electric vehicles, as well as a variety of mainstream consumer segments, each with different motivations and degree of propensity to adopt different types of technology (Anable et al. 2011).

There are also differing post-purchase adoption issues with electric vehicles. An ethnographic study from the UK (Brady 2010) points out that adopters of electric vehicles are challenged by a lack of support with regard to servicing and maintenance of the car, and not by expected issues such as limited recharging facilities. The study concludes that the current market for electric vehicles consists predominantly of multi-vehicle suburban households, who do not mind DIY repairs and servicing. Furthermore, the study describes electric vehicles as a niche technology, as those who adopt electric vehicles can be categorized into classical innovators and/or early adopters. According to the study, drivers are citizens with a high appreciation of energy issues seeking to reduce energy use in their everyday lives (Brady 2010). For example, the electric vehicle drivers express a feeling of wellbeing and less guilt.

Similarly, Jansson (2009) concludes that potential electric vehicle consumers have either a strong pro-environmental orientation or a strong inclination to own this new technology. In general, consumers prefer cars that contribute to their self-realization process. This tendency can be assumed to influence the factors that make electric vehicles socially acceptable (Anable et al. 2011).

Accordingly, factors like information, demonstration and opportunities to test electric vehicles in everyday life could help consumers with purchase decisions and assure them that electric vehicles are compatible with their daily needs. Routines in which electric vehicles differ from conventional vehicles, such as charging or re-routing for limited driving distances, should be designed, communicated and supported by means of appropriate technical devices so that they are easy to manage in daily life. The conclusion is that the range of electric vehicle models should be oriented towards various user groups, so that the different user groups will be able to select the model which is most appropriate for them (Peters et al. 2011).

Despite a wider acceptance of the influence of social and behavioural factors on the adoption of electric vehicles, car manufacturers still emphasize the electric vehicle as a mainstream car in their communication to the public, portraying novel hardware as neither unfamiliar nor sensational, but as safe, familiar and comfortable. This reflects the perception of consumers as close-minded about new technologies. Instead of embracing new energy technologies, it is thought that consumers rely on notions of tradition and familiarity when they make consumer choices, especially when dealing with hardware that requires high capital investment (Sovacool and Hirsh 2008).

Concluding on future challenges: understanding consumers in the smart grid

The smart grid is an emerging socio-technical system. Many ideas and expectations are associated with the term, but examples of large-scale deployment of smart grid solutions are few so far. Up to now, advanced metering systems (smart meters) have been the technology with the largest distribution in Europe, including Denmark. However, apart from simple and mostly web-based feedback services and remote readings of customers' electricity consumption, smart meters for more advanced applications on a larger scale have not been seen.

While the actual, full-scale employment of smart grid solutions is still limited, the number of research, development and demonstration projects is manifold. Different concepts and strategies are developing, particularly within the areas of energy saving (with feedback to customers about their electricity consumption) and load management.

The high degree of "interpretive flexibility" associated with the "smart grid" means that it is imbued with very different and sometimes conflicting interpretations of how solutions should be designed. One example is household load management and the question of who should manage and control consumption in the household. Some argue for remote control with as little active participation from residents as possible, while others work with designs that aim to involve residents actively through continuous information about real-time prices. Behind these different approaches lie different ways of conceptualizing residents and their interests.

Hitherto, initiatives within the development of smart grid solutions have tended towards a technology-centred design approach. New solutions are designed with a primary focus on the technical needs of the future electricity system, e.g. load management, and only a secondary focus on the interests and characteristics of the end-users. As a result, the end-user context is in most projects only weakly integrated in the design.

The technology-centred design approach involves the risk that possible "un-intended" side-effect uses might undermine the intended, systemic benefits of developing smart grid solutions. One example could be electric vehicles that are believed to play a key role in relation to "peak shaving" and the problem of fluctuating renewable energy production. However, few projects have studied the actual charging pattern of owners of electric vehicles. A potential problem could arise if owners recharge their cars when they come home from work in the early evening, which would coincide with the peak load between 17:00 and 19:00. In this example, the charging pattern would actually exacerbate the peak-load problem.

In this chapter, we have described how smart grid solutions might form a possible future scenario for a climate friendly energy system, while also describing the way that consumers should be assigned a central role in realizing the smart grid. However, as demonstrated through the examples of Danish projects and the review of consumer responses to electric vehicles, it is also apparent that there are many unanswered questions and challenges to the realization of the smart grid. Establishing the smart grid is about making changes in a large technical system, the existing energy system, which forms a huge complex of integrated economic, technical, institutional and cultural structures with vested interests from many actors. Up until now, the focus of research has been on the technical and economic aspects of developing this new infrastructure. However, we want to emphasize the importance of the cultural and social structures of the everyday lives of consumers as a decisive element in this transition. This importance is mutual: the smart grid will not be able to work if consumers' everyday practices are not integrated adequately into the solutions. But also vice versa: there are many relevant questions to ask of the smart grid solutions from a consumer policy perspective. These include questions of energy security, data security and anonymity in relation to the flow of data on household consumption, as well as rights and obligations related to the new possible roles of "prosumers", i.e. households being energy consumers and producers at the same time.

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